



Fly Ash For Highway Construction and Site Development

Introduction

The use of fly ash for structural fills, base course construction, subgrade improvements, backfills, grouting and coal mine applications has been limited in the United States. In 1988, approximately 50.9 million tons of fly ash were produced in the United States. Of this amount, only 1.2 million tons of fly ash were used in these applications. This represents only 2.3% of the fly ash produced in 1988, and 10.5% of the 11.4 million tons of fly ash utilized in 1988. In order to demonstrate the technical feasibility of using fly ash in these types of applications, the Electric Power Research Institute (EPRI) began a program in 1984 to prepare a report summarizing past demonstration projects, a marketing manual, and design and construction manuals. As part of this research effort, EPRI also sponsored six demonstration projects. The main purpose of the demonstration projects was to document the design, construction, and post-construction performance of fly ash used as structural fill for highway embankments, base course, and the recycling of flexible pavements. This paper overviews the marketing, design and construction manuals prepared as part of the project and provides an overview of the six demonstration projects.

Ash Production Rates

The current usage of coal by utilities in the United States results in the production of over 80 million tons of solid combustion by-products each year. An approximate doubling of coal usage in the United States within the next ten years has been predicted, which will only intensify the challenges associated with the proper disposal or utilization of the by-products. Stringent particulate removal requirements and increased use of desulfurization systems will further increase by-product volumes. The problem of effective utilization of coal ash has been given wide attention for at least twenty years in the United States. Although the effort devoted to the problem has led to some applications of demonstrated usefulness, the full utilization of coal ash has been hindered by lack of effective knowledge dissemination from field studies to potential users of coal ash, and by the obvious variability of the product. Extensive utilization of coal ash is both technically and economically feasible, yet less than a quarter of utility coal ash produced in the United States is presently being utilized.

In the United States, approximately 80% of the coal ash by-products are in the form of fly ash, which has a lower utilization rate than the bottom ash. In response to industry requests to improve the low rates of ash utilization, the Electric Power Research Institute initiated an ash utilization research and development program in 1979. This program has been divided into three principal areas:

- High-volume uses,
- Medium-technology uses, and
- High-technology uses.

High-volume uses include those fly ash products which are either large in quantity or use high percentages (over 50 %) of fly ash in a product. In addition, these products must not require a specified type or quality of fly ash, but must satisfy only performance specifications. High-volume uses are typified by highway related civil engineering applications. Medium-technology uses are defined as those which require that the fly ash



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satisfy a given specification, e.g., ASTM C618-83, and typically involve only a small percentage (5-20 %) substitution of fly ash in the product. These medium-technology uses also include cement pozzolans and bituminous fillers. High-technology uses are currently directed primarily at the extraction of the mineral value from the fly ash. This paper describes only the high-volume uses.

High Volume Ash Utilization Research

EPRI is undertaking a multi-year program to promote the bulk sale of coal ash in high volume applications, primarily in the highway construction sector. The project is specifically directed to applications that do not require a specific class or quality of fly ash. To date the EPRI demonstrations have focused on the first six of the applications listed below:

- Fills
- Embankments
- Backfills
- Hydraulic (CLSM) Fills
- Subgrade Stabilization
- Pavement Base Courses
- Landfill Cover
- Grouting
- Slurry Walls
- Soil Amendments

This paper outlines the principal components of the project and reviews the progress to date. The major components of the project include:

- Documentation of existing ash utilization projects
- Participation in demonstration projects sponsored by EPRI and host utilities
- Documentation of Federal Highway Administration (FHWA) and other non-EPRI sponsored projects
- Preparation of draft specifications with cooperation of State highway and environmental agencies
- Preparation of a Design Manual for Ash Utilization
- Preparation of a Construction Manual for Ash Utilization
- Development of a generic utility ash marketing program
- Preparation of brochures, films, and slides promoting ash use
- Educational seminars

A major objective of the EPRI ash utilization research project (RP 2422) is to promote the use of fly ash in highway construction applications to contractors, design engineers, and State highway departments. Since many of these groups consider coal ash a new or unconventional construction material, a major effort is underway to document the numerous successful applications of fly ash in general construction.

Using a literature review and telephone survey of utilities known to have used ash in the past, over 270 existing projects using fly ash in high volume applications in the United States and



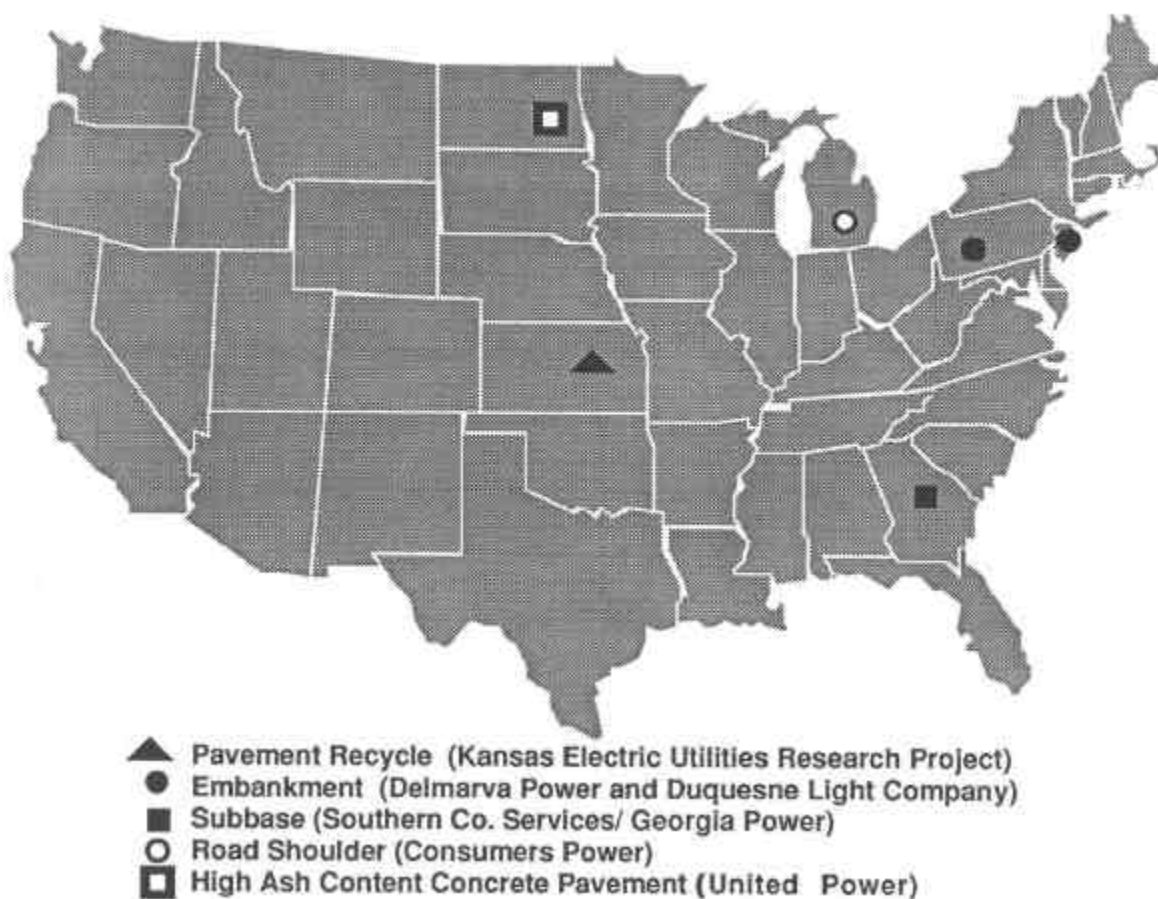
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Canada were identified as of 1987. Mail surveys were circulated to solicit information on additional projects from state highway agencies and other coal-burning utilities. Ten additional projects summaries were added to a revised edition of EPRI report CS-4446 (1) in 1987. These project summaries include available data on ash characteristics, details of construction, monitoring and performance. The project summaries are contained in brochures in loose-leaf form so that utilities and others using this report can select applicable projects when promoting a particular ash use.

An important component of the overall EPRI program is sponsorship of six new demonstration projects, particularly in those areas of the United States where ash has not been widely used but where considerable market potential and utility interest in ash utilization exists. EPRI expects that through these demonstration projects, potential customers and highway departments will recognize that power plant ash by-products are acceptable building materials and economic substitutes for other natural products now in use. The goal is increased use of fly ash throughout the United States due in part to these construction projects and improved receptiveness by state governments and highway departments to by-product utilization.

Figure 1
EPRI Ash Utilization Highway Demonstrations



The demonstration projects are structured to show the environmental and technological acceptability of ash utilization in road construction in a controlled and monitored segment of a highway. The field demonstrations have also served as test cases for a design manual (2)



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and a construction specification manual (3) developed for highway ash utilization. Near the end of the project, the design manual will be revised.

The EPRI sponsored field demonstration projects will be supplemented with information and data obtained from previous highway projects which used coal ash. This will provide information on long term durability and performance which otherwise would not be available in a five year project. Figure 1 shows the location and type of EPRI demonstration projects.

The program is designed to address concerns and impediments of each user group (design engineers, utility engineers, contractors, highway department specification writers etc.) through the development of specific work products. The work products published as reports are as follows:

- A summary of existing high volume ash utilization projects in the United States and Canada (CS-4446)(1).
- A design manual for high volume uses of dry (conditioned) and flowable fly ash (CS-4419, Vols. 1&2)(2).
- A construction manual for high volume uses of ash in highways (CS-5981)(3).
- Georgia Highway Ash Demonstration Construction Report (CS-5225) (4).
- A generic marketing program manual based on successful utility marketing programs in the United States (CS-4763)(5).
- Fly Ash Construction Manual for Road & Site Applications (CS-5982)(6).
- Laboratory Testing of Fly Ash Slurry (CS-6100)(7).
- Michigan Highway Shoulder Construction (GS-6155)(8).
- Georgia Highway Ash Demonstration Final Report (GS-6175)(9).
- Pennsylvania Highway Embankment Construction Report (GS-6431)(10).
- Kansas Pavement Recycling Project Construction Report (GS-6460)(11).
- Delaware Embankment Project Construction Report (GS-6481)(12).
- Delaware Embankment Project Final Report (GS-6540)(13).

A description of the significant results in the completed and on-going demonstration projects sponsored by EPRI are included below.

1. DELAWARE ASH RAMP EMBANKMENT PROJECT

In this project nearly 10,000 tons of stockpiled (landfill) fly ash from Delmarva Power and Light Company's Edge Moor Station were used to construct the main access ramps for a new interchange to Interstate Route 495 near Wilmington, Delaware, during June of 1987.

Under contract to EPRI, Delmarva Power and Light Company (DPL) and its subcontractor, VFL Technology Corporation (VFL) provided a comprehensive documentation of the placement and performance of the ash embankment over a three-year time period. Included in the monitoring program are background laboratory analyses of representative fly ash samples, on-site testing of fly ash placement and compaction behavior, collection and analysis of groundwater and runoff samples in the vicinity of the ash fill area, periodic core sampling and laboratory analysis of material from within the ash fill, settlement monitoring, preparation of summary reports, and the production of a 20-minute videotape record of the project.



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Background Testing

Laboratory tests were performed on representative ash samples to establish basic physical, chemical, and engineering properties. All physical properties were in the typical ranges for fly ash.

Composite ash samples were analyzed for chemical composition and leachate characteristics, by both the EP Toxicity procedure and ASTM Method A. All concentrations for each test method were below the RCRA toxicity limits.

The tests of engineering properties determined that maximum dry density values ranged from 66 to 70 pounds per cubic foot at optimum moisture content values from 32 to 37 percent. Very little difference was noted between standard and modified compaction results. Permeability test results are between 10^{-4} and 10^{-5} centimeters per second. Internal friction angles are in the 17° to 18° range, which is comparatively low. The compression index values are between 0.035 and 0.02. California Bearing Ratios for stockpiled fly ash are 5.3 at 0.1-inch penetration and 6.7 at 0.2-inch penetration.

Construction

Construction began with the removal of muck and placement of Type B select borrow material, a free-draining sand and gravel to prevent the capillary rise of groundwater from beneath the fly ash embankment.

The Type F borrow was placed in 2-foot high lifts with a minimum top width of 6 feet. Fly ash was placed and compacted within the 2-foot high dikes and built up to the top of the dikes. Then another 2-foot high containment dike was constructed on both sides to contain the fly ash fill. The process was repeated until the top of the new fly ash ramp was attained.

Fly ash was placed and compacted according to DEL DOT specifications. The required density of 95% of maximum dry density was achieved by 4 passes of a 10-ton vibratory roller, without addition of water at the project site. A photograph of the fill placement operation is shown in Figure 2 below.



Figure 2:
Placement of
the ash
embankment
on I-495 Near
Wilmington,
Delaware.



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Periodic moisture checks of the fly ash stockpile by a Speedy moisture tester indicated that the moisture content was in the 25 to 30 percent range, which was below the optimum moisture content. The stockpile was sprayed as necessary to maintain moisture content.

Ash moisture content and field density were monitored throughout the construction period to confirm that adequate compaction was achieved.

Environmental Monitoring

The short-term effects of the project on local groundwater quality were evaluated by four monitoring wells, four permeate collection drains, and by collection and analysis of runoff and leachate. No significant environmental effects were observed during the two year post construction monitoring period.

Post-Construction Monitoring

The project was monitored through June 1989 to evaluate post-construction performance of the ash embankment. The monitoring program includes observations of settlement, standard penetration tests and laboratory testing of ash samples extracted by test borings. The samples were tested for the same physical and engineering properties as the initial testing. In addition, undisturbed samples were analyzed for unconfined compressive strength, triaxial shear strength and falling head permeability. Results of these tests have been correlated with in-place penetration resistance values from the test borings. The in-place soil bearing characteristics indicated that the fly ash fill has in-place soil bearing characteristics that are equivalent to a well compacted granular soil. The average moisture content of the ash was somewhat higher than the moisture range within which the fly ash was initially placed. There was less than one-eighth of an inch settlement measured at each of the settlement plate locations, indicating that the fly ash fill performed as well as conventional borrow materials. The successful placement and performance of the fly ash fill in Interstate 495 demonstrated that fly ash is an acceptable embankment construction material. The final report was published in November 1989 as GS-6540(13).

2. PENNSLYVANIA ASH EMBANKMENT PROJECT

Approximately 350,000 tons of coal fly ash and 2200 tons of stabilized FGD sludge (Poz-O-Tec) were placed in a highway embankment along Interstate 279 in Pittsburgh, PA.

The embankment is approximately 250 feet wide, 1500 feet long and up to 50 feet deep. A 5-foot (min.) thick soil cover encapsulates the embankment to minimize infiltration of surface water and to prevent erosion of the ash. A one-foot thick blanket underdrain of No. 57 stone with a protective soil cover were placed at the base of the embankment to direct groundwater to an existing 84-inch diameter concrete storm sewer. No. 57 stone-filled vertical drains were placed through the lower soil protective layer at approximately 150 foot intervals to drain any water that infiltrates the fill.

Background Ash Testing

Laboratory tests were performed during the design phase to determine the physical, engineering and chemical characteristics of the fly ash and Poz-O-Tec. These tests included



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moisture content, grain-size distribution, specific gravity, moisture-density relationship, shear strength, consolidation characteristics, permeability and leachate analysis.

Construction

The placement of fly ash and Poz-O-Tec followed PaDOT standard procedures of soil placement. The material was trucked to the site in covered dump trucks, end dumped, spread in a uniform 8-inch loose lift thickness by a track-propelled dozer, and compacted with either a 15-ton smooth drum vibratory self-propelled roller (Raygo 600) or a 20-ton pad foot vibratory self-propelled roller (Dynapac CC50PD). The ash was compacted to a minimum 97 percent of maximum dry weight density as determined by PTM No. 106, Method B (ASTM D698 Standard Proctor Density).

Approximately four to six passes of the vibratory rollers were necessary to achieve the required compaction. The Raygo roller operated at its maximum 1550 VPM and the Dynapac machine operates near the resonant frequency of 2000 VPM. Figure 3 is a photograph of the Dynapac roller. Both rollers traversed at a controlled rate that provided for maximum compaction efficiency. These operating parameters were established by field trial during initial ash placement. The fly ash was found to be most efficiently compacted using vibratory compactors operating near the fly ash resonant frequency of about 2,000 vpm. The use of heavy 20-ton vibratory compactors extended the moisture range over which fly ash was satisfactorily compacted. The ash surface would pump under vehicle wheel loads when compacted to maximum dry density at moisture contents above the optimum moisture content. The compaction step for the Poz-O-Tec material was found to be more sensitive to moisture content than the fly ash material. It did not harden as quickly at temperatures below 40°F.

Prior to the shipment of ash, the moisture content was monitored using Speedy moisture test equipment to assure that the ash delivered to the site was within the range for proper compaction.



Figure 3: Dynapac roller used in Pennsylvania Ash Embankment Project.



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In-place density tests were conducted using both nuclear and sand cone methods. The sand cone tests were used to calibrate the nuclear densometer equipment and to establish the best depths of penetration for direct transmission testing. Speedy and oven dry moistures were used to determine dry unit weight. A manual calculation of the dry density was performed from these data and compared to PTM 106 maximum dry weight density determinations.

Clegg meter readings were also recorded to monitor dynamic impact resistance of the fill and to evaluate the relationship of impact resistance to moisture-density performance.

Performance Monitoring

The settlement and embankment deformation were monitored during construction and two years thereafter by two sets of settlement stations and horizontally oriented slope indicator installations. To date, settlement is very close to predicted values.

Four piezometers were also placed in the lower sections of the ash embankment to monitor development of the phreatic surface. The settlement plates and piezometers were monitored at intervals of 30, 60, 90, 180 and 360 days following construction and semi-annually in the second year.

Prior to placement of the soil cover, the bearing capacity of the compacted ash was determined at four approximately equally spaced locations along the embankment. At each location, a plate bearing test was taken to determine the modulus of subgrade reaction (K) used in the design of rigid pavements. Comparison field California Bearing Ratio (CBR) tests were also performed nearby.

Standard penetration testing were conducted at two locations to determine penetration resistance. The tests will be conducted once in each of the two years of the monitoring program.

Shelby tube samples were taken at two depths at each of the two locations of the Standard Penetration Tests. The Shelby tubes provide undisturbed samples that were tested in the laboratory for density, moisture content, triaxial shear, consolidation, and permeability. The project successfully demonstrated the use of fly ash and stabilized FGD sludge as fill material in highway embankment construction. The embankment was designed using conventional state-of-the-practice design methods for earth fills and was constructed in accordance to the standard Pennsylvania DOT specifications. The fly ash embankment has performed as well as, or better than design estimates with respect to settlement, deformation, and slope stability.

Environmental Monitoring

Groundwater was monitored using two wells installed in the ash embankment above the underdrain. Samples are also being collected directly from the underdrain. Based on laboratory EP toxicity and ASTM leachate testing of random samples of the ash, no adverse groundwater effects are anticipated.

Post-construction monitoring will continue through 1990. The project was sponsored by Duquesne Light Company and EPRI, with the cooperation of the Federal Highway Administration and the Pennsylvania Department of Transportation. Duquesne Light



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Company estimates the savings from the use of the by-product material at \$662,000. In addition, the contractor and the State DOT each saved an estimated \$100,000.

3. GEORGIA HIGHWAY ASH SUBBASE DEMONSTRATION

In cooperation with the Georgia Department of Transportation, Southern Company Services, Georgia Power Company and the Georgia Environmental Protection Agency, a three-part test section of a two-lane State highway was designed to include ash as a subbase and base course material under the road. Figure 4 is a photograph of the cement-treated fly ash base course being spread and compacted. The investigators designed and installed environmental monitoring facilities and collected background pre-construction groundwater characteristics. Since completion of the construction in Summer 1985, investigators have monitored pavement structural behavior and groundwater from nearby wells. This demonstration project utilized ash in three slightly different ways, namely:

1. Lime-fly ash stabilized subgrade soil layer, using fly ash that had been collected and stored dry.
2. Cement-treated fly ash base course, with fly ash that had previously been ponded before excavation and placed in a landfill.
3. Cement treated pond ash (fine and coarse) base course.



Figure 4: The cement treated fly ash base course being spread and compacted in Georgia Project.



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Laboratory mixture design studies were used to develop the relative proportions of ash and stabilizer additive necessary to meet the compressive strength quality criterion established for each of the ash mixes. For the LEA, 8% lime and 14% fly ash were used while for the CPA and CFA, the cement content was 11% and 14% respectively. Overall it was found that the CPA base was the easiest of the special ash sections to construct. Both Georgia DOT and contractor personnel were favorably impressed with the material.

The project's final report (EPRI Report GS-6175)(9) presents the details of the site selection, design and construction of the demonstration project. Laboratory mixture design studies were used to develop the relative proportions of ash and cement necessary to meet the compressive strength quality criterion established for the ash mix. Special specifications were developed for use in control of the construction of the special ash test section. The main goal was to achieve a minimum of 400 psi compressive strength (after 7-day curing) in the vacuum saturation test and to keep the frost heave under 0.5 inches for a standard test specimen. Extensive monitoring of the construction process is documented in the aforementioned EPRI report.

4. MICHIGAN ROAD SHOULDER REPLACEMENT WITH COAL ASH

In cooperation with the Michigan Department of Transportation, Consumers Power Company and the Michigan Department of Natural Resources, a test section of a four-lane State highway was designed to include ash as a base course material under the road shoulder. Consumers Power Company supplied the high-carbon content, dry hopper ash for the demonstration. The project team tested several ash samples to identify the proportions of ash and cement required for a minimum 400 psi compressive strength (after a 7 day curing) and to keep frost heave to under 0.5 inches. Mix design and compaction specifications were developed for an aggregate-free cement stabilized fly ash road base, which was placed under a 1,500 foot long test section of a road on both sides of a four-lane state highway. Protocols were developed for mixing, handling, and placement of the fly ash mixture in the field. Groundwater monitoring facilities collect background pre-construction data. Figure 5 is a photograph of the portable pugmill mixer used in the project.



Figure 5:
The Portable
Pugmill
Mixer used
in the
Michigan
Project.



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Since completion of the construction in Summer 1987, investigators have monitored the structural behavior of the overlaying pavement and groundwater quality conditions. Test results showed that a cement content of 12% by dry weight was sufficient to meet the strength-durability criteria and to minimize frost heaving. The thickness of the fly ash-cement base was required to be ten inches after compaction and trimming to meet the highway department design criteria. The target field density was specified as 98% of maximum dry density based on the Modified Proctor test. The fly ash mixture was placed using a conventional traveling spreader box and compacted using both rubber tire and steel wheel rollers. Although the specified cure time was seven days, the fly ash cement base developed sufficient strength after three days to support the paving machinery. The asphalt concrete leveling course was placed over the fly ash shoulder seven days after construction and the surface wearing course was finished three days later.

EPRI report (GS-6155)(8) presents the details of the site selection, design and construction of the demonstration project. Utilization of high-carbon fly ash as a highway base course poses an attractive market opportunity. The Michigan Department of Transportation, which is responsible for 9,600 miles of federal and state trunkline highways in that state, expects to complete 140 miles of road shoulder replacement annually. This shoulder replacement program could utilize 300,000 tons of fly ash annually, or one-eighth of the total annual production in southern Michigan's lower peninsula.

5. KANSAS HIGHWAY RECYCLED PAVEMENT DEMONSTRATION PROJECT

Approximately 70% of the low volume and local access roads in the US require upgrading. Highway maintenance and construction budgets are extended to the limit and the taxpayers are resisting tax hikes. It is a situation, in which coal ash can play an important role.

Both Class C and Class F fly ash have been successfully used to recycle existing pavements, typically low volume local roads maintained by municipal or county agencies. Class F fly ash requires the use of Portland cement or lime as a stabilizing agent, while Class C ash is normally used alone. An EPRI demonstration project conducted by the Kansas Electric Utilities Research Program (KEURP) involved pavement recycling using Class C fly ash.

First, a pavement recycling machine pulverizes the existing road surface and up to several inches of subgrade, mixing the material and redepositing it in its original location. Depending on the machinery used and the maximum size aggregate in the existing pavement, this will result in a maximum aggregate size of 1 to 2 inches.

If it is necessary to reduce the plasticity of the subgrade material that is mixed with the pulverized pavement, lime is sometimes spread at a rate of 3 to 5% and mixed into the pavement/subgrade blend using the recycling machine. This blend is typically allowed to cure for 24 hours before adding the fly ash.

The fly ash is spread using a dump truck and spreader box (any ash), a pneumatic tanker truck (dry Class C or Class F ash), or a paving machine (conditioned Class F ash). Fly ash is usually 10-20% of the dry weight of the final material. If Class F fly ash or a Class



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C fly ash with low reactivity is used, Portland cement or lime may be used to provide cementation. This may require an additional mixing step if the fly ash and cement/lime are not preblended before application. The final mixing is performed using the recycling machine. Ash shown in Figure 6, water is added directly through the recycling machine to bring the material to the optimum moisture content for compaction. Layer compaction is accomplished with a vibratory roller, and a pneumatic tire or smooth-drum roller is used to smooth the surface.



Figure 6: Water Addition in Bomag Pavement Recycler.

A coat of asphalt emulsion is usually applied to seal the surface and retain moisture in the recycled material to allow it to cure properly. The required curing time depends on the curing rate of the material. A chip-and-seal coating or an asphaltic concrete overlay wearing surface is typically provided. The demonstration project showed that the process is viable and can be accomplished using available equipment. A Bomag MPH 100 recycler was used for pulverization and mixing at three project locations in Kansas. The degree of pulverization achieved, in general, appeared to be better than was accomplished for the material used in the laboratory study which preceded construction. The compaction procedures and equipment established for the project provided a higher degree of compaction than originally anticipated.

In addition to the direct benefit of improved economy, fly ash pavement recycling provides several additional advantages over alternative pavement upgrade methods:

- Since pavement material is not removed from the site, a disposal area is not necessary.
- There is little change in grade from the original road surface.



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- Scarce aggregate resources are not required.
- Fly ash that is used does not require disposal.
- Construction progresses quickly.
- Petroleum-based asphalt is not required
- The final material has a high modulus and good durability.
- Rutting is not a problem.

Limited groundwater monitoring was also conducted during this project. The ashes used in the project were sampled prior to construction and analyzed for total concentrations of 23 metals as well as levels of those metals readily leachable as indicated by the EPA EP toxicity test method.

Composite samples of the soil subgrade underneath the stabilized fly ash were taken from three depth levels (0-2 inches, 2-4 inches, and 4-6 inches) prior to construction and also analyzed for concentrations of the 23 metals. Analytical results did not indicate potential for significant groundwater quality impairment. The results showed that the trace metals migrated only a short distance vertically downward from the pavement into the subgrade soil.

Pavement recycling using fly ash is a relatively recent development, which shows potential to provide local agencies an economical road rehabilitation alternative. Since the construction of this project at three locations in Kansas in 1987, over 400 miles of pavement recycling using Type C fly ash has been done in Kansas and Oklahoma. The EPRI sponsored demonstrations in Kansas have now been in service for over three years, and have exhibited no signs of deterioration due to traffic or weather conditions. The EPRI report (GS-6460)(9) presents the details of the site selection, design and construction of this demonstration project. EPRI plans to publish design and construction procedures pertaining to pavement recycling using fly ash in the final edition of the *Fly Ash Design Manual for Road and Site Applications*, EPRI CS-4419, which is due in 1991.

5. POZZOCRETE CONCRETE PAVEMENT DEMONSTRATION

The highway demonstration project of most interest to the concrete design community is the one completed in North Dakota in which a Class C fly ash was used to replace 70% of the cement used in the concrete pavement. Fresh Class C fly ash from the Coal Creek Generating Station, located near Falkirk, North Dakota, was used to make concrete for paving several roads and parking lots at the station and for use in a flowable-slurry backfill material for filling several culverts. In all 5288 cubic yards of concrete and 35 cubic yards of slurry were placed in the summers of 1988 and 1989. The high-cement replacement concrete had good working characteristics, and no significant problems were encountered while placing and finishing the pavement. The 35-day compressive strengths measured for the concrete placed in June 1989 generally exceeded 3500 psi.

The overall objectives of the project were as follows:



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- To document the use of fly ash in a high-volume application involving cement replacement (approximately 70%) in concrete and the use of fly ash slurry backfill material.
- To demonstrate the environmental and technological acceptability of fly ash utilization in road construction in a controlled and monitored construction project.
- To assess the long-term durability and performance of fly ash as a high percentage replacement for cement in concrete.

During the summers of 1988 and 1989, approximately 23,800 square yards of eight-inch thick concrete pavement, containing 1042 tons of fly ash were placed at the project site. Figure 7 is a photograph of the Pozzocrete being place for the pavement. The original concrete design mix for this project specified the replacement of 70% of the Portland cement with fly ash. The ingredients for this design are listed under Mix #1 in Table 1. Mix #1 was used from the beginning of the construction until August 31,1988. Mix #2 was used from September 2, 1988, until the end of 1988. Mix #2, which had about 15% more cement added than Mix #1 was used because much of the concrete that was placed in the summer of 1988 showed test strengths below the specified 3500 psi 35 day curing period. The specifications for the concrete pavement are shown in Table 2. The construction of the pavement was resumed in 1989, the original mix was used again, because that particular mix design had been successfully used for a previous pavement construction job at the Coal Creek Station. The concrete was batch mixed off-site and trucked about 20 miles to the Station. The concrete components were separately added to the trucks and mixed while being transported to the site. At the construction site, the concrete was placed from the ready-mix trucks directly into the pavement forms and additional spreading was done by hand. A vibrator was used to consolidate voids.

Table 1: Concrete Mix Design

<u>Design Mix Components</u>	<u>Amount Added per Cubic Yard of Concrete</u>	
	Mix #1	Mix#2
Cementitious Materials:		
A. Type II Portland Cement	170 lbs	194 lbs
B. Coal Creek Type C Fly Ash	<u>394</u> lbs	394 lbs
Total	564 lbs	588 lbs
Admixture:		
ProtexAEA	4.2 oz	4.2 oz
Procrete-N	11.5 oz	11.5 oz
Fine Aggregate	1330 lbs	1250 lbs
Coarse Aggregate (1.5"- .75")	730 lbs	740 lbs
Coarse Aggregate (.75"-#4)	1110 lbs	1120 lbs
Coarse Aggregate (Total)	1830 lbs	1860 lbs
Water, Net	240 lbs	240 lbs
Water / Cement Ratio (W / A+B)	0.43	0.41
Slump	4 inches	4 inches
Cement Factor (Nominal A+B)	6.0sk/yd	6.25 sk/ yd
Air Content (Calculated)	6.0%	6.0%



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Table 2: Concrete Mix Specifications

<u>Parameter:</u>	<u>Acceptable Range or ASTM Specification</u>
Compressive Strength at 35 days	3500 psi, minimum
Slump	4 to 5 inches
Air Content	5-7%
Cement	Type I-II Portland Cement, conforming to ASTM C 150
Fly Ash	Type C Fly Ash, conforming to ASTM C 33
Fine Aggregate	Passing # 4 Sieve, conforming to ASTM C 33
Coarse Aggregate	1.5"- #4, conforming to ASTM C 33
Protex AEA	Air Entraining Agent, conforming to ASTM C 260
Procrete-N	Water Reducing Agent, conforming to ASTM 494
Water	Clean and conforming to ASTM C 94

The finishing process followed standard North Dakota highway procedures. The finished concrete sections were protected from moisture loss for at least seven days using a membrane curing compound. Joints were sawed in the pavement at appropriate intervals within 24 hours or next working day after the pour. The joints were sealed in accordance with the "Standard Specifications for Road and Bridge Construction" of the North Dakota State Highway Department. The joint sealer conformed to AASHTO M173. Expansion joints were placed using a filler material conforming to ASTM C 1751, with steel reinforcing bars were used to tie the pavement sections together across the expansion joints.

Concrete compressive strength was measured using proctor-sized cylinders cast on each day that concrete was placed. The concrete cylinders were made in accordance with ASTM C 31 and tested in accordance to ASTM C 39, with the exception that additional samples were cast to permit testing after 3, 7, 21, 35, and 84 days of curing. Some of the concrete cylinders, particularly those cast in August 1988, did not meet the minimum strength requirement of 3,500 psi at 35 days. The reason for these low strengths has not been determined. All the samples cast in 1989 with the same mix design have met the strength requirement.

Concrete beams were also cast on five days for testing of the flexural strength (ASTM C 78), freeze-thaw resistance (ASTM C-666), and sulfate resistance of the concrete (Bureau of Reclamation Method). The North Dakota Highway Department typically requires that the flexural strength of concrete reach a minimum value of 500 psi before a highway can be opened to traffic. The results indicate that the high-volume fly ash concrete pavement had almost attained the required 500 psi value after 28 days. Concrete samples were also



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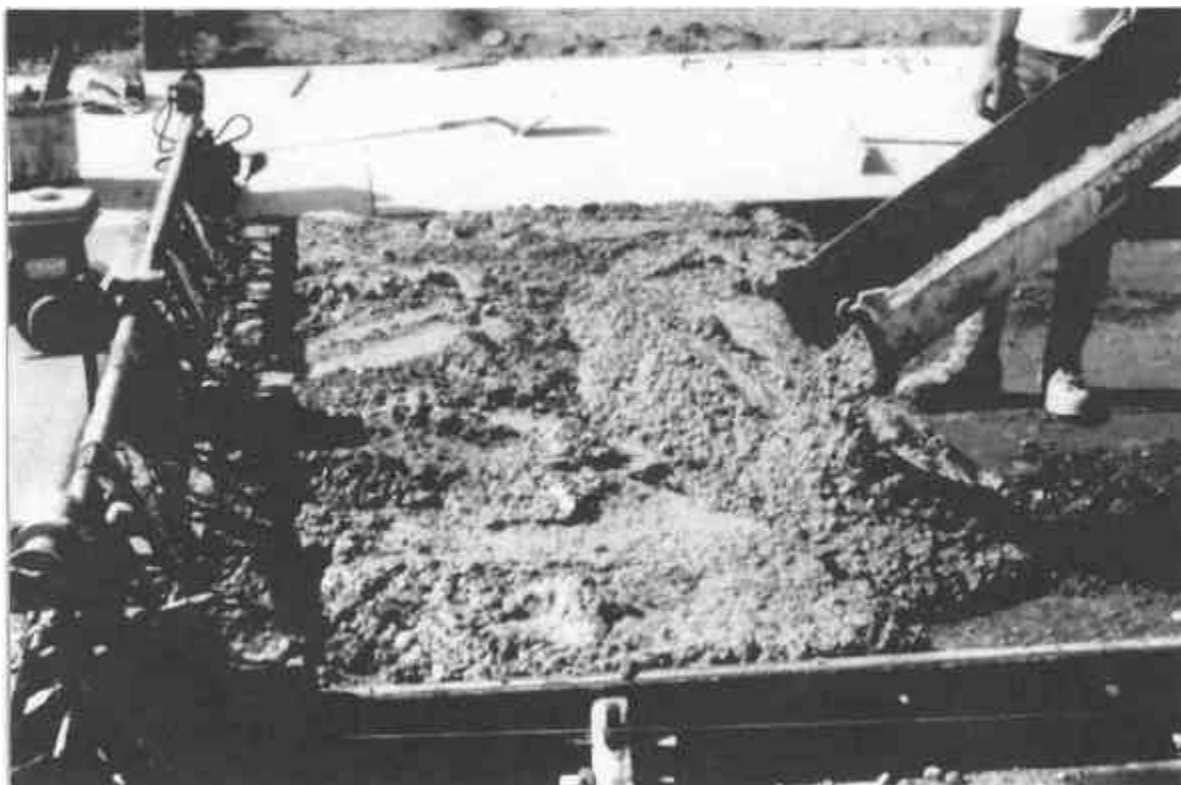


Figure 7: Placement of Pozzocrete 70% Ash/Cement Pavement in North Dakota.

subjected to freeze-thaw durability testing. The results indicated good freeze-thaw resistance since most of the dynamic moduli at the conclusion of the test were over 100%. Sulfate resistance testing also yielded positive results, with the specimens not expanding more than 0.6% of original length. None of the specimens tested expanded, rather they all shrank slightly. The results of this test program will be presented in detail in an EPRI report to be published in early 1991.

COMPACTION OF ASH EMBANKMENTS

The compaction equipment selected for the construction of coal ash use projects contributes to the success of the project and may provide cost savings for the owner or contractor by reducing construction time and by allowing the coal ash to be placed over a broader range of moisture contents. Experience has shown that vibratory rollers operating near the resonant frequency of coal ash (typically 1800 to 2000 vpm) can achieve satisfactory compaction with less effort and over a broader range of moisture contents than generally required when using static compactors. To provide guidelines for equipment selection, EPRI is sponsoring a test program to evaluate the compaction characteristics of a coal ash using state-of-practice compaction equipment. Most of the available information on coal ash compaction is either in the form of case studies of projects, test programs with a limited combination of variable parameters chosen, or older studies conducted outside the U.S. with coal ash not typical of U.S. ash.

The test program is a cooperative effort involving EPRI, Ingersoll-Rand Company, and a local utility. The field portion of the program was conducted in Summer 1989 at a western Pennsylvania ash disposal site. The EPRI contractor, GAI Consultants, Inc., provided



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supervision and technical support for the test program. Three vibrating compactors were used: a 12-ton single smooth-drum vibratory soil roller, a 13-ton single padfoot-drum vibratory soil roller, and a 10-ton tandem smooth-drum vibratory asphalt roller. These machines were operated at various frequencies to compact coal ash at moisture contents ranging from the minimum required to prevent dusting to slightly over standard Proctor optimum moisture content. Densities were measured after various numbers of passes and at several depths up to 12 inches. These procedures were used to define the relationships of energy attenuation with depth, frequency, density, and moisture content.

The two soil rollers were chosen primarily for their similarity and for their variable frequency capabilities. Essentially, the difference between the two compactors is the addition of pads on the drum of the padfoot roller. Thus, the test program evaluated the difference in compaction performance between padfoot and smooth-drum vibratory rollers. The asphalt roller (with variable vibration amplitude) was included to evaluate roller performance when amplitude and centrifugal force are limited to minimize surface distress. This is important for pavement base applications where a torn surface may contribute to poor pavement performance.

Results from the test program will be included in the final edition of the *Fly Ash Design Manual for Road and Site Applications*, EPRI CS-4419 to be published in early 1991.

FLOW ABLE COAL ASH BACKFILLS

The EPRI highway ash demonstration project included laboratory work to develop mix designs for flowable ash applications which was published as *Laboratory Testing of Fly Ash Slurry*, EPRI Report CS-6100 (7). The North Dakota demonstration project contained a small test of a pipe backfill to test the concept under field conditions. Although not a highway application, the Delmarva Power Company saved \$614,000 by using flowable coal combustion by-product backfill in the replacement of cooling tower facilities at their Indian River Station. The old unit No. 4 cooling tower had deteriorated due to chloride intrusion to the point where it was condemned. Initially, the replacement tower, cold water return flume, and hot water circulating pipes were designed to be supported by deep foundations over 6 to 11 foot thick soft organic peat deposits located at a depth of 15 to 16 feet below grade. Concern for driving the piles in close proximity to the existing deteriorated tower, a high groundwater surface, and the resulting high cost of deep foundation alternatives prompted the evaluation of using shallow foundation alternatives for supporting the flume and circulating water pipes.

The analysis showed that by using lightweight, stabilized flowable coal combustion by-product backfill, the cold water return flume and circulating hot water return pipes could be supported on floating or compensated shallow foundations. Essentially, the principle of compensated foundations involves over excavating the in-place soil to such a depth that the weight of soil removed would approximately equal the weight of the backfill and structures. Thus, the stresses induced by the new structure and backfill on the underlying peat deposits would remain equal to, or slightly less than the pre-load stresses induced by the in-place soil, and very little, if any, consolidation of the organic peat layer would be anticipated.

The compensated foundation designed called for overburden to be removed in the flume and pipe trench to two feet above the existing ground water level. A two foot layer of flowable



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fill was placed in the trenches for trench bottom stabilization. The flume was constructed on the two foot bedding. The pipe was set on saddles then additional flowable fill was placed approximately one half the pipe height for bedding the pipe. Both the pipe and flume trench were completed by backfilling and/or covering with a bottom ash blend.

In addition to using the flowable fill in the compensated foundation design, the light weight and labor saving characteristics of the flowable fill was used to advantage in backfilling around the tower pile caps that were supported by short, 40-foot long pile groups.

Four mix designs were used for the flowable backfill. The three basic mixes were specifically designed to provide strengths ranging from 100 to 300 psi as follows:

- 100 psi mix - 5% cement and 95% fly ash
- 200 psi mix -10% cement and 90% fly ash
- 300 psi mix -15% cement and 85% fly ash

The 100 psi mix was used for backfilling around the tower pile caps, flume, and pipes while the 200 and 300 psi mixes were to be used for flume support and pipe support, respectively. A mix containing bottom ash was used to provide a protective cover for the circulating water pipes and on the flume sides and access ramp. Due to low temperatures during construction, the 200 psi mix was used to fill around the pile caps to accelerate the construction schedule.

Approximately 12,800 cubic yards of flowable backfill were used. Phase 1, which included backfilling around the pile caps consumed 8,500 cubic yards. Phase 2, the placement of pipe and flume support and pipe and flume backfill consumed another 5,300 cubic yards.

Due to the labor and time savings offered by using flowable coal combustion by-product backfill, Delmarva was able to place the new cooling tower facilities in service on November 1, 1989, ahead of schedule, while realizing a savings of approximately \$614,000.

ROLLER COMPACTED CONCRETE

The technology of roller compacted concrete (RCC) has undergone rapid advancements in the past few years. As fly ash has been shown to be a beneficial additive in RCC mixes, the advancement of RCC may open a new market for fly ash utilization. RCC applications were not included in the demonstration projects supported by EPRI, although a new chapter on this application is being added to the final edition of the *Fly Ash Design Manual for Road and Site Applications*, EPRI CS-4419, which is due in early 1991.

RCC is most easily described by comparisons to other types of Portland cement concrete. Unlike conventional concrete, RCC is stiff when fresh. Compared to lean concrete, however, RCC has enough strength upon curing to resist frost action and abrasion. Thus it can be used as a pavement wearing surface.

RCC mixes have cement contents similar to conventional mixes, but are placed at lower water contents. This high cement content - low water content gives the mix its initial stiffness and high cured strength. RCC mixes also differ from conventional mixes by aggregate gradation. RCC aggregates have a higher proportion of fine particles to reduce



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segregation. A significant portion of the fines can be fly ash. Fly ash can also contribute as a cement replacement and pozzolan.

The major advantage of RCC over conventional concrete is the ease and speed of placement. Because it is self-supporting, no formwork is needed. The RCC mix is normally spread with asphalt paving machine. No transverse joints are used. The surface is leveled with a tamping or vibrating screed, which may be equipped with oblique forms at either end to shape the edges of the pavement. The RCC is then compacted with a vibratory roller, which creates a dense mass and a smooth level surface. No hand finishing is needed.

To date, RCC has been used in pavements and dams. In pavements, 15 to 40% of the cement may be replaced with fly ash to improve the plasticity and compactability of the mix. In massive concrete dams, the heat of hydration can build-up, resulting in cracking. Partial replacement of cement with fly ash reduces the rate of hydration, allowing time for heat to dissipate. For this reason, fly ash has been used to replace up to 70% of the cement in RCC dams. Several high volume dams and pavements have been constructed with RCC which incorporated fly ash.

As indicated by the work on highway demonstrations, flowable fills and RCC, EPRI's primary goal is to significantly increase the utilization of ash in high volume applications. To accomplish this goal, a work program has been developed which will produce a number of products designed to remove impediments and concerns and close communication gaps between the various groups whose cooperation and support are essential to increasing ash utilization. In 1991 EPRI will begin a highway demonstration project using coal combustion by-products created from emerging technology processes.

SUMMARY

EPRI has been actively seeking to increase the utilization of coal ash through an applied research and development project begun in 1979, and has a multi-faceted program underway over the next several years to continue the research in this area. The high volume applications in highway construction uses, medium technology uses in cement and concrete, ACC building blocks, and the high technology mineral extraction process development make up the triad of ash utilization research at EPRI. As part of RP 2422 highway demonstrations were constructed in Georgia, Pennsylvania, Delaware, North Dakota, Michigan and Kansas. Design Guidelines for the use of coal ash in both a dry conditioned form and as a wet slurry were issued in 1986 (CS-4419), and in 1988 a Construction Specifications Manual (CS-5981) have been issued as part of this project. Although limited post-construction data are presented in this paper, evaluation of the ash material quality and pavement structural behavior / performance together with an extensive environmental monitoring program are documented in the EPRI reports described herein. Those reports show that to date there have been no cases of impact on the groundwater quality as a result of the use of coal ash in the highway applications.



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This coal ash utilization case study is a selection of the Coal Combustion Product Partnership. For more information, consult the C2P2 web site at <http://www.epa.gov/epaoswer/osw/conserve/c2p2/>